on the Gunpowder River, Seneca Creek and Middle River while a pH of 7.8 was found in Chesaspeake Bay waters (Table 1). On 19 August pH levels below 6 were found in the Gunpowder River and Middle River while bay waters had a pH of 7.3 (Table 2). On 16 September only the Gunpowder River had a pH below 6 (Table 3). A 16 October survey found pH patterns similar to the 16 September survey (Table 4). Stations 2 and 3 in Gunpowder River and 11 in Middle River were where low pH was most commonly found.

Three separate groups of larval striped bass were raised in the Crane Aquaculture Facility during 1985. Two groups arrived as one day old larvae on 19 April and 29 April. The last group arrived as 5 day old larvae on 15 May. Some larvae were held in tanks buffered with sodium bicarbonate to a pH above 6.2 while ambient water pH dropped to 5.3. Larvae of groups 1 and 2 were moved from the buffered tanks before ambient pH fell below 6.1 (buffered tanks ≥6.5). Group 3 larvae were the eldest held in buffered tanks (buffered tanks ≥6.2, ambient tanks ≥5.3), until the age of 25 days. Approximately 40% of the striped bass of groups 1 and 2 were held in buffered tanks until 13 May. Approximately 67% of group 3 were held in buffered tanks until 4 June. No apparent difference in survival of larvae was seen between tanks receiving buffered or

Table 3.—Results of water quality samples taken in a survey on 16 September 1985. Station locations are shown on Fig. 1.

Station	Depth	pH	Temp. (°C)	Salinity (%)
1	Surf.	6.4	20.0	5.0
	Bott.	6.3	19.0	6.0
2	Surf.	6.5	20.3	6.0
	Bott.	5.3	19.0	7.0
3	Surf.	6.3	20.5	7.0
	Bott.	6.2	19.3	7.5
4	Surf.	7.5	21.5	8.0
	Bott.	7.3	19.5	8.0
5	Surf.	7.0	21.0	8.0
	Bott.	7.0	19.7	8.0
6	Surf.	6.4	20.0	8.0
	Bott.	6.9	19.5	8.0
7	Surf.	6.5	20.0	8.5
	Bott.	6.5	19.1	9.0
8	Surf.	7.0	19.8	8.0
	Bott.	6.7	19.3	9.0
9	Surf.	6.9	20.0	8.2
	Bott.	6.9	19.5	9.0
10	Surf.	7.5	22.0	8.0
	Bott.	7.3	21.0	10.0
11	Surf.	6.1	20.4	9.0
	Bott.	6.2	19.8	9.0
12	Surf.	7.6	21.0	8.5
	Bott.	6.8	20.0	8.5

Table 4.—Results of water quality samples taken in a survey on 16 October 1985. Station locations are shown on Fig. 1.

Station	Depth	pH	Temp. (°C)	Salinity (%)
1	Surf.	7.5	18.3	4.0
	Bott.	6.5	18.3	5.0
2	Surf.	6.1	18.0	6.0
	Bott.	5.8	18.0	6.0
3	Surf.	7.0	18.0	7.0
	Bott.	7.1	18.3	7.0
4	Surf.	7.4	19.0	7.5
	Bott.	7.4	18.8	8.0
5	Surf.	7.1	18.7	7.5
	Bott.	7.2	18.7	7.5
6	Surf.	7.1	19.0	8.0
	Bott.	7.1	18.7	7.5
7	Surf.	7.3	19.3	8.0
	Bott.	7.1	19.3	8.5
8	Surf.	7.2	19.0	8.0
	Bott.	7.3	19.0	8.0
9	Surf.	7.2	19.0	8.0
	Bott.	7.3	18.7	9.0
10	Surf.	7.5	19.0	8.0
	Bott.	7.5	19.0	9.0
11	Surf.	6.1	19.0	8.5
	Bott.	6.4	19.0	8.5
12	Surf.	6.7	18.7	8.0
	Bott.	6.5	18.7	8.0

Table 5.—Striped bass age at initial exposures to low pH levels.

pH	Age (Days) at Initial Exposure Group I	Group II	Group III
>7.0	1	1	8
7.0–6.5	12	3	5
6.5–6.0	24	15	26
6.0–5.5	28	19	28
5.5–5.0	46	37	45
<5.0	102	93	78

Table 6.—Contributions to the Binary Coded Wire Tagging Project during 1985.

Facility	Number of Fish	Percent	Weight of Fish (lb)	Percent
Manning (MD)	4723	2.5	189*	1.3
Crane Aqua. (MD)	40672	21.8	6977	49.8
Horn Point (MD)	6405	3.4	237**	1.7
Harrison Lake (VA)	61840	33.1	3092*,†	22.1
McKinney Lake (NC)	7404	4.0	370†	2.6
Edenton (NC)	56851	30.4	2842†	20.3
Orangeburg (SC)	3939	2.1	197†	1.4
Frankfort (KY)	5092	2.7	113*	0.8
Total	186926	100.0	14017	100.0

*Estimates, personal communication, J. Stringer, MDDNR
**Estimates, personal communication, R. Harrell, Univ. MD.
†Estimates, personal communication, C. Wooley, USFWS

ambient waters. Striped bass were exposed to pH levels below 6.5 at ages of 15, 24 and 26 days, below 6 at ages of 19 (group 1) and 28 days (groups 2 and 3), and below 5.5 at ages of 37, 45 and 46 days (Table 5). Survival during 1985 was the best observed for the history of the facility.

The U.S. and Wildlife Service and the Maryland Department of Natural Resources established a binary coded wire tagging project for striped bass stocked into the Chesapeake Bay. During 1985 eight facilities located in Maryland, Virginia, North Carolina, South Carolina and Kentucky produced 186,926 fish for the tagging Program (Table 6). The Crane Aquaculture Facility contributed 21.8% of the number and 49.8% of the biomass of striped bass tagged (Table 6), indicative of good production during 1985.

Discussion

Occurrence of low pH

The belief that low salinity concentrations sufficiently buffered estuarine waters to prevent sustained pH shifts has been proven unjustified by this study. It has been stated that a salinity of 2-10 ppt would buffer sufficiently to negate pH fluctuations[5]. The ambient waters from Seneca Creek were found to drop in pH from above 7 to below 5.5 from April to June 1985 (Fig. 2). The pH level remained consistently below 6 from the last week in May until the third week in August.

As the pH dropped the salinity increased from 2 ppt (April) to 5 ppt (May-Fig. 2) and some pH sample levels remained below 6 in September even though salinity increased to 8 ppt. These data show that low pH levels occur in oligohaline waters and can exist for extended time periods.

The cause of the low pH during 1985 is not known. Four possible mechanisms can be proposed: 1) freshwater inflow from the Susquehanna River; 2) acid deposition from rain; 3) decaying material causing increased hydrogen sulfide; and 4) ground water infiltration.

The discharge of the Susquehanna River at the Conowingo Dam ranged from approximately 200 to 940 m^3/min from April to August 1985, a dry year, as compared to 500 to 2760 m^3/min for the same period of 1984, a wet year. This inverse relationship between river flow and pH eliminated major drainage inputs as possible causes of the observed decline.

Local acid rain can be eliminated by noting the results of the water quality surveys conducted during 1985 (Fig. 1 and Tables 1-4). Isolated pockets of embay-

ments gave pH levels below 6. Stations in the bay and often upstream of the isolated pockets gave much higher pH levels (≥6.5) indicating a local, isolated source for the low pH waters. The relative constancy of the low pH over long periods also suggests other mechanisms for its development and maintenance.

Decomposition of organic material from local aquatic weed beds and nutrient enriched waters could lead to a pH decline by causing anaerobic conditions and the release of hydrogen sulfide. We did not observe low dissolved oxygen in the facility, but did not measure this parameter on our surveys. It seems unlikely this mechanism can explain the low pH.

Groundwater in the region can be acidic[9,10,11]. It is possible ground water is entering at this area, but we did not observe any decline in salinity of the bottom waters near areas of low pH. No definitive answer is available on the cause of the pH decline. Studies are continuing to gain information on possible sources of the acidic conditions.

The low pH during 1985 was not an isolated occurrence for the area. A study during 1980, another dry year, reported low pH in September when pH levels below 6 were found at salinities of 6-7 ppt in the same areas as the present study[12]. The findings of these studies raises questions about the source and occurrence of low pH waters in oligohaline reaches of Chesapeake Bay. Low pH may be more common than previously thought in poorly buffered estuarine waters.

Striped bass survival

Despite low pH in the source waters of the Crane Aquaculture Facility, 1985 was one of the best years for survival of striped bass larvae cultured in the facility. The levels of pH described as toxic in the literature indicated larvae should not have survived[2,3,6,7]. Studies have established that survival of striped bass larvae is enhanced by low salinity[3,7,8,13]. Low salinity may reduce toxic effects associated with low pH levels.

Larval fish cultured to juvenile stages in the Crane facility during 1985 arrived in three groups. Two groups arrived as one day old post-hatch while the last group arrived as five day old post-hatch. Approximately 40% of groups 1 and 2 and approximately 67% of group 3 were held in buffered waters. Larvae survived pH below 6 from ages of 19 (group 1) and 28 days (groups 2 and 3). This is below the tolerance range cited in the literature[6,14]. The final group of fish were held in water buffered to pH levels above 6.2 while ambient intake waters were as low as 5.3. No difference was observed between the larvae cultured in buffered or ambient waters indicating little, if any, toxic effects due to low pH.

The fact that 1985 was a good year for producing striped bass at the Crane Aquaculture Facility is supported by the percent contribution the facility made to stocking efforts through the Binary Coded Wire Tagging Project (Table 6). Most of the facilities involved contributed the majority or all of their production to the tagging project. The Crane Facility's contribution was 40,672 fish for 21.8% of the numbers tagged and 49.8% of the biomass (Table 6). The large biomass (highest of all facilities) in comparison to the number (third largest) of fish indicates the excellent condition of the fish produced at the Crane Facility under low pH conditions in oligohaline waters.

The pH toxicity studies for striped bass have been conducted in freshwater because most spawning occurs in freshwater reaches of rivers and most hatcheries utilize freshwater sources. Doroshev[2] found sudden pH shifts of 0.8 to 1.0 units were toxic to striped bass larvae in freshwater. Setzler et al.[14] listed the pH tolerance range of larval striped bass (<20 mm) as 6-9 and a tolerance range for young fish of 6-10. Hall et al.[3] speculated that aluminum concentrations at a pH of about 6.3 caused mortalities for larval striped bass in the Nanticoke River, Maryland. However, the experimental controls of this study were maintained at salinities of 1-3 ppt while the treatments were at 0-0.9 ppt. Since

low salinities enhance survival the results of Hall et al. may be partially explained by salinity differences rather than toxic effects of pH and aluminum. Palawski et al.[13] found low salinity (1 and 5 ppt) decreased the toxic effects of several organic or inorganic contaminants.

It is possible low salinty levels would alleviate the effects of lowered pH (via acid deposition or other sources) near striped bass spawning areas. Striped bass spawn mainly in the first 25 miles of freshwater with good flows[7]. Eggs and larvae drift with currents (until larvae are about 5 days old) and many reach oligohaline areas of the estuary. The saltier areas may counteract the impacts of acid deposition that has been hypothesized as the cause of striped bass stock decreases in scientific[3] and popular[4] literature. If oligohaline waters offer refuge for striped bass from the toxic effects of acid deposition, it is unlikely that the drastic declines in stocks could be caused by acid deposition.

More research must be conducted on the interaction of acid inputs in oligohaline waters, especially poorly buffered estuaries, and related toxic effects. The belief that small salinity concentrations will buffer waters from pH fluctuations is no longer viable. However, the low salinity waters may not exhibit the toxic effects for low pH and contaminants seen in freshwaters. Research needs to be conducted on the interaction of salinity with toxicants to answer questions on possible impacts in oligohaline waters.

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Euplotes iliffei n.sp.: A new species of *Euplotes* (Ciliophora, Hypotrichida) from the marine caves of Bermuda.

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ABSTRACT

Euplotes iliffei n.sp., a new anchialine species of *Euplotes* from the marine caves of Bermuda is described. *E. iliffei* has a dorsal interkinetal argentophilic reticulum of the multiple to complex type with a tendency toward 4 interkinetal polygonal areas. Like other members of the group of *Euplotes* that have a frontoventral cirri in pattern I the VI/2 cirrus is missing. *E. iliffei* also has a very pronounced notch in the upper border of the dorsal surface.

Introduction

The limestone platform that makes up the Bermuda Islands is composed of Pleistocene and recent, marine and eolian limestones which overlay a mid-ocean volcanic sea mount. Most of Bermuda's caves were formed when sea level lowered during periods of glaciation as a result of dissolution by slightly acidic percolating ground waters. The caves were subsequently flooded by marine waters when

sea level rose during postglacial periods (1,2). Extensive horizontal cave passages, some being more than 2.0 km in length, have been explored and mapped utilizing sophisticated cave diving techniques (3,4).

Recent studies on marine animals inhabiting these subterranean anchialine habitats has revealed the presence of diverse endemic macro-invertebrate faunas (5,6,7). However, during these earlier cited comprehensive cave faunal surveys, samples containing possible cave protozoa were not collected. Newer studies are currently examining these same caves for protozoa, and a rich and diverse anchialine ciliated protozoa fauna has been established (8). Included among the new ciliated protozoa are several species of *Euplotes*, one of which is described here.

In the literature over 80 species and varieties of *Euplotes* have been described in the last 200 years, many of which are now considered junior synonyms as reviewed by Hill, 1980 (9). Curds (10) in his 1975 guide to the genus listed 51 different species of *Euplotes*. In the last few years several new species have been described. Jones and Owen (11) described *E. nana* and Ten Hagen (12) characterized *E. palustris*. *E. terricola* originally described by Penard (13) is no longer considered a member of the genus *Euplotes* because of the spatial arrangement of the frontoventral and transverse cirri and the presence of many left marginal cirri. Thus, we now consider there to be 52 valid species in the genus *Euplotes*. This paper describes the first anchialine species of *Euplotes* (*Euplotes iliffei* n.sp.) from the marine caves of Bermuda.

Materials and Methods

Euplotes iliffei n.sp. was collected along with many other protozoa in Wonderland Cave. This cave, located in the Hamilton Parish, Bermuda, was previously known as Whitby Cave. The cave was open to the public until the 1940's when it was closed as a commercial tourist cave. A small entrance building gives access to a steep set of stairs which lead to the first room of the cave. This large room contains a sea level lake which is about 60 m long by 12 m wide. A 50 m long underwater passage connects this room to a second smaller air chamber. No known human-sized passageways connect the Wonderland Cave system with Castle Harbour, the nearest body of water which is 420 m from the inland entrance of the cave (14).

Ciliated protozoa were collected in the surface waters of the entrance room of Wonderland Cave using small protozoan traps baited with tuna fish (15). At the time of collection the water temperature ranged from 20.2°–21.2°C and the surface salinity was 12‰. *E. iliffei* was maintained in Millipore filtered sea water (20‰) with wheat grains at 20°C after initial isolation on tuna fish and associated decay bacteria from the protozoan traps.

For light microscope observations of cortical ciliary structures and their morphogenesis during cell division, the cells were stained by a modification (16) of the protargol method of Jerka-Dziadosz and Frankel (17). To demonstrate specific cortical structures of the argyrome, preparations were made using Corliss' (18) modification of the Chatton-Lwoff technique of silver impregnation. Borror's nigrosin-$HgCl_2$-formalin stain and fixative (19) was used to observe cortical sculpturing. For determining nuclear shape, the cells were fixed in 2.0% glutaraldehyde, washed in distilled water and afixed to cover slips with Mayer's albumin and feulgen stained following the procedures of DiStephano (20). Drawings were prepared with a Nikon drawing instrument and the terminology of the ventral ciliary structures were based upon the topographical and developmental characteristics as previously outlined for other *Euplotes* species (9,21,22).